論文 / 著書情報
Article / Book Information

題目(和文)	生分解性金属インプラント用Mg-Zn合金の組織制御と表面改質
Title(English)	Microstructure Control and Surface Modification of Mg-Zn Alloys for Biodegradable Metallic Implant Materials
著者(和文)	DINH NGOC PHAM
Author(English)	Dinh Ngoc Pham
出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第12098号, 授与年月日:2021年9月24日, 学位の種別:課程博士, 審査員:小林 郁夫,多田 英司,史 蹟,曽根 正人,生駒 俊之
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第12098号, Conferred date:2021/9/24, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	Materials Science and Engineering	系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of (Engineering)
学生氏名： Student's Name	PHAM NGOC DINH		指導教員（主）： Academic Supervisor(main)	小林 郁夫
			指導教員（副）： Academic Supervisor(sub)	多田 英司

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Magnesium (Mg) is considered as one of the most promising candidates for biodegradable. Although having many great advantages, the practical use of Mg as implant materials is limited because pure Mg has low mechanical strength and rapid degradation in physiological environment. Alloying elements are effective methods to improve both mechanical strength and corrosion resistance of Mg. However, for the biomedical applications, the selection of alloying element for Mg must also be considered with regards to the biocompatibility. Zn is considered as an appropriate candidate because Zn is biocompatible and biodegradable element, and Zn addition also improve both mechanical strength and corrosion resistance of Mg. This study aims to enhance the mechanical and corrosion property as well as the biocompatibility of Mg-Zn binary alloys for biodegradable orthopedic implant materials throughout microstructure control and surface modification.

Chapter 1 "General Introduction", the motivation to develop Mg alloys for biodegradable implant materials, current development and remained problems of Mg alloys for biodegradable orthopedic implants are introduced. The objectives and methodologies of the thesis are also established.

Chapter 2 "Influences of Zinc content and solution heat treatment on microstructure and corrosion behavior of Mg-Zn binary alloys", the corrosion behavior of as-cast and solution heat treated (T4 treatment) on the corrosion behavior of Mg-xZn alloys (x=1, 3, 5 and 7 wt%) were investigated. Results of the corrosion tests revealed that the volume fraction of (α-Mg + MgZn) eutectic cell and Zn segregation influences the corrosion behavior of Mg-Zn alloys more dominantly than the Zn content. The (α-Mg + MgZn) eutectic cell and Zn segregation were formed along the grain boundaries and dendritic arms in the as-cast alloys and were almost disappeared by T4 heat treatment. As a result, the corrosion resistance of the T4-treated Mg-Zn alloys become higher than that of the as-cast Mg-Zn alloys with the same Zn content. The results suggested that the optimal Zn content for corrosion resistance of as-cast Mg-Zn alloys was 1 wt% and the Zn content range which can provide relatively high corrosion resistance was widened to 1-5 wt% by T4 treatment.

Chapter 3 "Influences of Zn content and solution heat treatment on mechanical properties and mechanical integrity of Mg-Zn alloys in Hanks' solution", the mechanical properties of as-cast and T4-treated Mg-Zn binary alloys were evaluated by micro-Vickers hardness test and compression test. It was revealed that the compressive strength and hardness of as-cast Mg-Zn alloys increased with Zn content. The enhancement was attributed to 3 factors: (i) the refinement of grain size, (ii) solution of Zn in Mg matrix and (iii) formation of (α-Mg + MgZn) eutectic cell which contributed to the grain boundary strengthening, solid solution strengthening and second phase strengthening, respectively. Zn segregation at grain boundaries enhanced the grain boundary sliding, which was presumably contributed to the high failure strain of as-cast alloys. The T4 treatment caused the dissolution of eutectic cell and Zn segregation, thereby reducing the strength and strain of the Mg-Zn alloys. The mechanical integrity was investigated by compression test of samples after prescribed immersion period in Hanks' solution. The deterioration of mechanical properties showed a correlation to the degradation rate and corrosion form of Mg-Zn alloys. The Ac-1Zn and T4-1Zn alloys showed only 5% and 10% loss of compressive strength after 4 weeks immersion in Hanks' solution, and are expected to remain

higher strength than cortical bone for at least the next 12 weeks.

Chapter 4 "Influence of substrate microstructure on uniformity of hydroxyapatite coating and corrosion behavior of coated Mg-Zn alloys", hydroxyapatite (HAp) coatings were formed on as-cast and T4-treated Mg-xZn (x = 1, 5, and 7 wt%) alloys by a chemical solution deposition method. The uniformity of HAp coatings showed an enhancement with finer particle size and lower volume fraction of (α-Mg + MgZn) eutectic cells and Zn segregation. The Mg-1Zn sample showed a defect-free HAp coating, while the HAp coating of the Mg-7Zn samples showed cracks preferentially over the eutectic cells causing micro-galvanic corrosion with the matrix. Initially, the corrosion rate of the HAp-coated alloys was governed by the uniformity of HAp coating, and eventually it was dominated by the corrosion resistance of substrate alloys after the HAp coatings irreversibly broken. Ultimately, the volume fraction and size of (α-Mg + MgZn) eutectic cells and Zn segregation governed the corrosion behavior of the HAp-coated Mg Zn alloys. The HAp-coated Mg-1Zn alloy showed 2-4 times lower corrosion rate than other alloys after 1 day and 4-10 times after 14 days of immersion. The uniform HAp coating reduced corrosion rate of Mg-Zn alloy by 45%. Consequently, the HAp coating effectively improved the corrosion resistance of Mg Zn alloys with low volume fraction of (α-Mg + MgZn) eutectic cells and Zn segregation.

Chapter 5 "Enhancement of corrosion resistance and in-vitro biocompatibility of Mg-Zn alloys by carbonate apatite coating", B-type carbonate apatite (CAp) coatings were formed on as-cast and T4-treated Mg-xZn (x = 1, 5, and 7 wt%) alloys by modifying the previously developed HAp coating solution in Chapter 4. The CAp coating grew uniformly on the alloys with a thickness of 1.1-1.3 μm and did not show cracks or pores on 30 μm sized eutectic cells. The CAp coating retarded corrosion of Mg-Zn substrates for the first 3-5 days in Hanks' solution. Polarization resistance (Rp) of the CAp-coated alloys was 10-90 times and 1-70 times higher than the uncoated and hydroxyapatite (HAp)-coated alloys, respectively. After the coatings were partly broken, the corrosion rate of CAp-coated alloys was strongly influenced by the substrate alloys. The CAp coated alloys showed 40-60% and 25-45% lower 14-day average corrosion rate than the uncoated and HAp-coated alloys, respectively, in the immersion test. The CAp coating significantly enhanced the viability of osteoblastic MC3T3-E1 cells on the Mg-Zn alloys for 72 h compared to the uncoated and HAp-coated alloys. The cell densities on CAp-coated alloys were similar for 72 h regardless of substrate alloys. Therefore, the CAp coating can be a superior coating candidate for corrosion-control and biocompatibility improvement for biodegradable Mg alloys.

Chapter 6 "General conclusions", the conclusions obtained in each chapter are summarized The corrosion rate after 1-day immersion of Ac-1Zn/HAp alloy was 25-50% that of other alloys, and the corrosion rate after 14-days immersion of Ac-1Zn/HAp alloy was 10-25% that of other alloys.